Invited Paper

Sub-THz quasi-optical wave control components

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Abstract: In applications to the plasma fusion, material diagnostics, particle acceleration, radar and communication, at frequencies approaching the THz region, the standard microwave transmission and control components need to be replaced with their oversized, quasi-optical, analogs.

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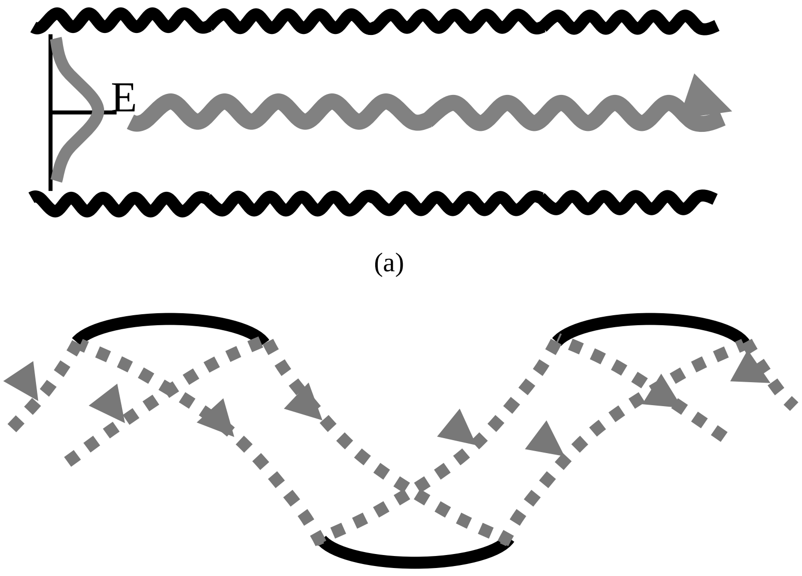
1. Introduction

At frequencies below ~30 *GHz*, we use simple reliable waveguides and cavities of cross dimensions commensurable with the wavelength. However, at scaling of such components to higher frequencies we meet enhancing difficulties: the loss enhancement and the RF breakdown threshold decrement. These difficulties may be, naturally, avoided by using components which cross dimensions are much larger than the wavelength. However, to keep the RF field coherence in such oversized structures, we need to provide a mode selection. Going this way, we arrive to the quasi-optics.

2. Oversized waveguides

Of course, in a waveguide representing a metallic tube, the RF loss may be reduced and the RF breakdown may be excluded, if the waveguide is taken broad enough (for example, in the circular cross section waveguide, especially attractive is the H_{01} mode – with zero electric field at the waveguide surface). However, in reality, any irregularities of such a waveguide, in particular, junctions between sections, produce spurious modes. For this reason, in present-day experimental systems, especially at high RF powers, people prefer using mode filtering waveguides: corrugated metallic tubes (Fig. 1(a)) or mirror lines (Fig. 1(b)) [1-5]. These waveguides, operating at quasi-Gaussian modes, admit easy mutual couplings.



(a)

(b)

Fig. 1 Quasi-optical waveguides.

3. Quasi-optical mode converters

At relatively low frequencies, usual waveguides operating at different modes are mutually matched by transitions where higher order modes cannot propagate. The latter condition cannot be satisfied, if a high frequency is combined with a high power. In such cases, the following methods of mode conversion may be used:

Selective wave scattering [1], [3], [6] . The method may be exemplified with transformation of one mode of an axis-symmetrical waveguide into another mode of the same waveguide (Fig. 2). Both the input and the output modes are assumed to have rotating transverse structures with azimuthal indexes m_{in} and m_{out} and axial wave numbers h_{in} and h_{out} . These modes may be selectively coupled by an $\overline{m}$ -entry helical corrugation of the waveguide surface under conditions

$$\overline{m} = m_{out} - m_{in},$$

$$\frac{2\pi}{d} = h_{out} - h_{in},$$

where d is the axial period of the corrugation. By analogy with beats between coupled oscillators, the input mode is totally converted to the output one at a proper length of the corrugated section.

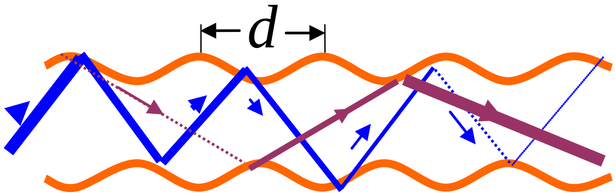


Fig. 2 Selective scattering of one mode to another mode in a corrugated waveguide.

Ray bunching [1], [3], [7-8]. In this case, the primary waveguide mode is approximated with a system of rays, the waveguide is asymmetrically cut, and downstream radiated rays are reflected in a necessary direction by properly shaped mirrors. To enlarge the percentage of the desirable (usually Gaussian) contents in the radiated wave pattern, the metallic surfaces are synthesized by using quasi-Maxwell equations. (Fig. 3),

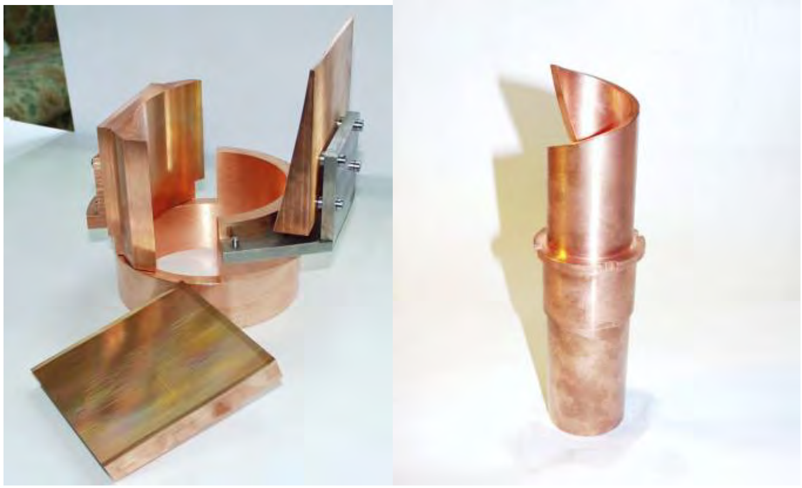

(a) (b)

Fig. 3 Elements of antenna converting a high-order gyrotron mode to a Gaussian beam.

4. Polarizers

If a wave beam is incident to a metallic grating [9] which period is small compared with the wavelength, we may present this wave as a sum of two waves: E- and H- polarized relative to the grating grooves. These waves penetrate between grooves at different effective depths and so, at the reflection, acquire different phase shifts. As a result, a linear polarized incident wave may turn circular polarized after the reflection and vice versa.

Two successive gratings may be composed into an universal polarizer [2-3] (Fig. 4): by rotations of these corrugated reflectors, any incident polarization can be converted into any desirable one.

Fig. 4 An universal polarizer combined with a miter bend (courtsy by V. Belousov).

5. Directional couplers

If a grating period is commensurable with the wavelength, the incident plane wave may be scattered into a number of diffraction maximums [9]. In particular, a shallow grating can direct the main energy of the incident wave into the mirror direction and a small part of the energy into the -1-st diffraction maximum. Such a grating can function as a bi-directional coupler [3] (Fig. 5): one channel gives a signal proportional to the forward wave and another channel gives a signal proportional to the wave reflected from the load.

Fig. 5 A bi-directional monitoring coupler implemented into a miter bend.

6. Isolators

Standard isolators (e.g., Faraday rotators) usable at relatively low frequencies cannot withstand high RF powers when scaled to the millimeter wave band. A robust quasi-optical isolator capable to function as a high power antenna duplexer (Fig. 6) [10-11] may be composed of two metallic gratings: a polarization separator (a version of the Littrow grating [9]) and a polarizer. The duplexer (Fig. 6) operates in the following way:

- The transmitter radiates a linear polarized wave. Reflected from the polarization separator into the mirror direction, the transmit wave keeps the linear polarization. Downstream, after reflection from the polarizer, the wave turns circular polarized and, finally, is emitted through the antenna.

- At the wave reflection from the target, the RF field rotation is assumed to be unchanged. But it is equivalent to the change of the field polarization relative to the wave propagation direction (for example, if the incident wave is left-polarized, the reflected wave is right-polarized). As a result, the echo wave, received with the antenna, after reflection from the polarizer acquires the linear polarization orthogonal to that of the transmit wave. Due to this, further downstream, the receive wave is forwarded by the polarization separator not into the transmitter, but into another direction - there we put a receiver.

Fig. 6 W-band duplexer (transmit-receive isolation -45 *dB*, bandwidth 8%).

7. Quasi-optical resonators

Resonators capable to operate at high powers and high frequencies may be composed of mirrors; input and output wave beams may be coupled to such a resonator by a mirror corrugation. Resonators of the sort [2-3], [11] may function as RF filters, pulse compressors (Fig. 7) and resonant rings.

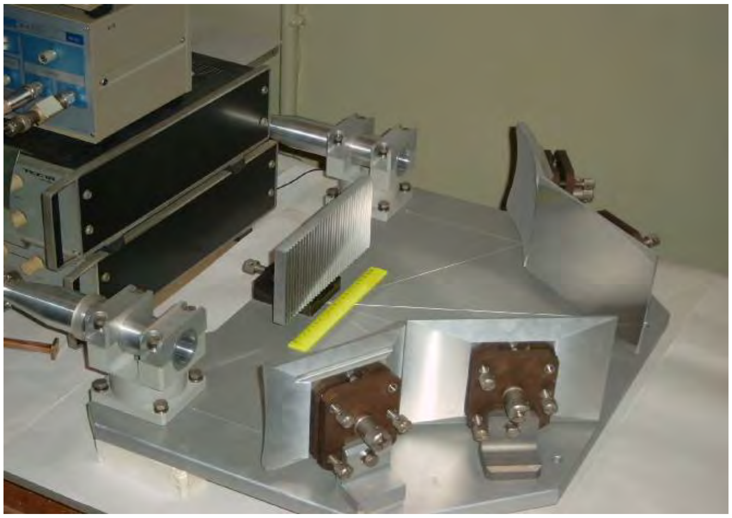


Fig. 7 A SLED-type RF pulse compressor.

A quasi-optical resonator with two corrugated mirrors may function as a diplexer: capable to combine or separate waves having, correspondingly, resonant and non-resonant frequencies. One of applications is the FADIS [11-12] (Fig. 8) representing a diplexer fed with wave beams from two frequency-controlled gyrotrons. At one combination of the gyrotron frequencies, the combined wave beam is radiated from one output of the FADIS; when the frequencies are reversed, the combined wave beam is radiated from another output of the FADIS. In addition, the FADIS can be used to combine the electron cyclotron heating and current drive with measuring the electron cyclotron emission from the tokamak plasma [13-14]; that will be useful to suppress hydrodynamic plasma instability.

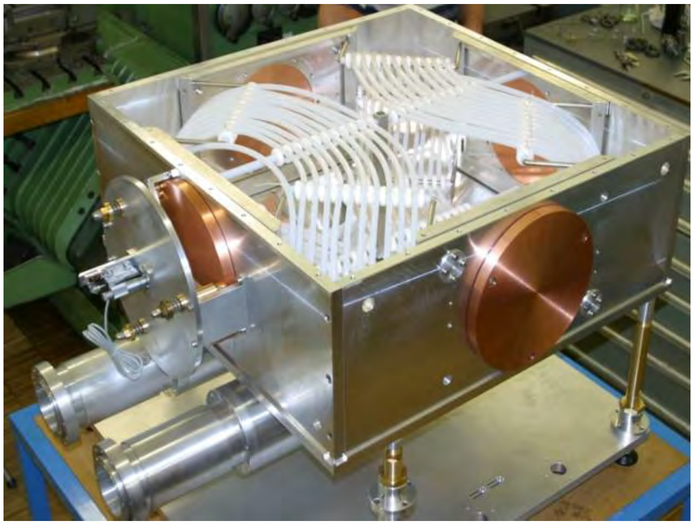


Fig. 8. FADIS planned for NTM stabilization at ASDEX Upgrade (courtsy by W. Kasparek).

A chain of diplexer represents a multiplexer [15] applicable to synthesize a broad frequency band of narrow sub-bands and, reciprocally, to distribute a broad-band signal between narrow-band channels.

8. Conclusion

The sub-terahertz quasi-optics is a field of interesting researches and promising applications.

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